Effect of environmental change after the 2011 tsunami on the population dynamics of Japanese tubesnout *Aulichthys japonicus* (Gasterosteiformes)

by

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Abstract. – The Japanese tubesnout *Aulichthys japonicus* Brevoort, 1862 is a small fish species, which lives in shallow coastal waters, especially in seagrass (*Zostera* spp.) beds. The fish is known for their unusual spawning behaviour of concealing their eggs in ascidians (*Halocynthia roretzi*). By studying the larval and juvenile fish fauna in a seagrass bed in southern Iwate, Japan since 2007, we observed that *A. japonicus* was a dominant species. On 11 March 2011, the seagrass bed was washed away by a Tsunami. The Japanese tubesnout population decreased after the Tsunami along with the loss of the seagrass bed, which also played an important role as a nursery ground for various coastal fishes. When the seagrass bed recovered from 2012, the tubesnout number also increased from 0.08 individuals/m^2 in 2012 to 0.21 individuals/m^2 in 2013. However, this number decreased to 0.05 individuals/m^2 in 2014. Assuming that the increase and decrease of ascidian individuals affected the tubesnout number, we counted the number of ascidians growing on the sea-wall adjacent to the seagrass bed. The ascidian number increased from 0 individuals/m^2 just after the Tsunami (2011) to 10 individuals/m^2 in 2013, then decreased to 8 individuals/m^2 in spring 2014 due to human activities. In 2015, all ascidians on the sea-wall were scraped off due to reconstruction, and tubesnout number decreased down to 0.05 individuals/m^2 in 2016 even though the seagrass bed has recovered. We observed some egg masses of tubesnouts in the ascidians removed from the sea-bottom. The results of the statistical analysis using model selection by AIC suggest that ascidian decrease led to tubesnout decrease. Therefore, the decrease of ascidians appears more effective than the decrease of seagrass area in reducing the Japanese tubesnout number. It is also suggested that human activities including restoration work disturbs the natural resilience after the disaster.

Key words
Aulichthys japonicus
Japan
Tsunami's effect
Population dynamics
Fish nursery
Resilience

Résumé. - Effets des changements environnementaux après le tsunami de 2011 sur les populations de trompes japonaises, *Aulichthys japonicus* (Gasterosteiformes).

La trompe japonaise *Aulichthys japonicus* Brevoort, 1862 est une petite espèce de poisson qui vit dans les zones littorales peu profondes, en particulier dans les herbiers à zostères (*Zostera* sp.). Ces poissons sont connus pour leur comportement de frai inhabituel consistant à cacher leurs œufs dans des ascidies (*Halocynthia roretzi*). Depuis 2007, nous étudions la composition des communautés de larves et de jeunes poissons dans les herbiers de l'Iwate du sud, au Japon, et nous avons observé qu'*A. japonicus* est une espèce dominante. Le 11 mars 2011, l'herbier a été détruit par un tsunami. Le nombre de trompes japonaises a diminué consécutivement à la perte de l'herbier qui joue un rôle important en tant que nurserie pour diverses espèces de poissons du littoral. L'herbier s'est rétabli dès 2012 et le nombre de trompes a augmenté de 0,08 individus/m^2 en 2012 à 0,21 individus/m^2 en 2013, puis est descendu à 0,05 individus/m^2 en 2014. Pensant que l'augmentation et la diminution du nombre d'ascidies ont eu une incidence sur le nombre de trompes, nous avons compté les ascidies sur le rempart de cordon littoral adjacent à l'herbier. Le nombre d'ascidies a augmenté de 0 individus/m^2 juste après le tsunami (2011) à 10 individus/m^2 en 2013, puis il est descendu à 8 individus/m^2 pendant l'été 2014 en raison d'activités humaines. En 2015, toutes les ascidies situées sur le rempart de cordon littoral ont été éliminées lors d'une reconstruction et la trompe a diminué jusqu'à 0,048 individus/m^2 en 2016, même lorsque l'herbier a été rétabli. Nous avons observé des masses d'œufs de la trompe japonaise dans les ascidies enlevées lors de la reconstruction. Les résultats de l'analyse statistique, réalisée à l'aide de la sélection du modèle de l'AIC, suggèrent que c'est la diminution des ascidies qui a entraîné la diminution des trompes japonaises et non celle de la surface de l'herbier. Notre étude montre aussi que des activités humaines y compris la restauration de la zone affectent la résilience.

INTRODUCTION

Zostera seagrass beds are meadows of *Zostera* spp., and *Zostera marina* is well known as a representative species, which grows on sandy and muddy sea-bottoms in coves of Japan. During the last five decades, seagrass beds have been recognized as nursery grounds of various fish species in Japan (Kikuchi, 1966; Koike and Nishiwaki, 1977; Kimura *et al*., 1983; Horinouchi *et al*., 1996; Horinouchi and Sano, 2000) and in other countries (see review in Gillanders, 2006). We have studied species composition and dynamics of larval and juvenile fish on a seagrass bed and in the surf zone in southern Iwate, Japan (Sato, 2007; Katayose *et al*., unpubl.). In these studies, we found that the Japanese tubesnout *Aulichthys japonicus* Brevoort, 1862 is one of the dominant fish species in this region, in contrast to other regions

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of Japan, such as Aburatsubo *in* Kanagawa (Horinouchi and Sano, 2000), Seto Inland Sea (Kamimura and Shoji, 2009; Mohri *et al*., 2013) and Mangoku-ura in Miyagi (Shoji and Morimoto, 2016). The relative dominance of this species in southern Iwate was probably due to specific local conditions specific with small scale beaches separated by rocky coast along a Ria coastline. Similar findings have been found in a sea cove in Cheju Island, Korea (Go and Cho, 1997). *A. japonicus* is a small teleost species, which lives in shallow coastal waters. It is known for its unusual spawning behaviour of concealing their eggs in the ascidian *Halocynthia roretzi* (Matsubara, 1971; Akagawa *et al*., 2008). In addition, *A. japonicus* is able to mature within a year and their lifespan is limited to two years (Ida, 1997).

On 11 March, 2011, our survey site was affected by a great Tsunami (ca. 20 m high wave), and land subsidence of approximately –1 m, resulting from the Great East Japan Earthquake (magnitude 9.0). This brought about various major environmental changes to the area. The seagrass bed was washed away causing various impacts on the shore, which plays an important role as a fish nursery. The shore regions are easily influenced by oceanic phenomena. To evaluate the Tsunami impact on fish nurseries implies the survey of the fish species that inhabit the region.

The present study focus on the population of a dominant fish species of the seagrass bed, *i.e*. the Japanese tubesnout, and surveyed its dynamics in relation with the environmental conditions of the site after the Tsunami.

MATERIALS AND METHODS

Survey site

Surveys were conducted in the seagrass bed at Namiita Beach, Okirai Bay, Southern Iwate, Japan (39°06'32"N; 141°49'47"E). Okirai Bay is 18.8 km^2, with a maximum water depth of 93 m, and is 2.2 km wide at the mouth of the bay. The beach is a small sandy beach in the inner part of the bay (Fig. 1); it usually experiences calm wave conditions because the beach is located between a rocky area and a seawall of the fishery port. The seagrasses were completely washed away during the 2011 Tsunami, and they started to re-establish from 2012 onwards.

Sampling

We collected all fish samples in the seagrass bed using a framed seine net (length = 4 m, height = 1 m, mesh size = 1 mm) with a 50 m rope. The net was designed for catching larval and juvenile fishes and consisted of a framed small beach seine net fitted with a central tapering cone ending in a tied cod end (Fig. 2). The net was pulled 50 m by the researchers over the seagrass bed. Sampling was carried out at low tides (during spring tide and at sunset in 2012-2014

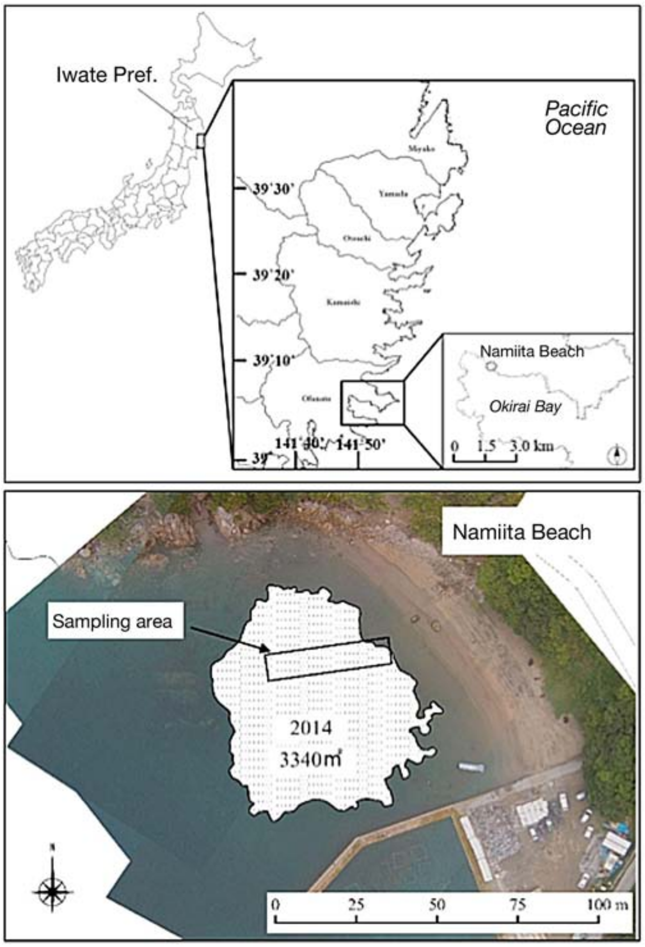

Figure 1. – Location of study area in Okirai Bay and position of the sampling site in Namiita Beach. The white dotted area shows the seagrass bed's area (m^2) in August 2014.

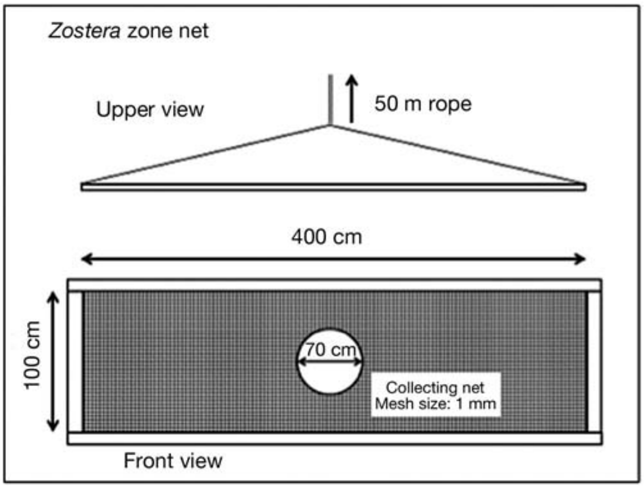

Figure 2. – Schematic illustration of the framed seine net used in the present study.

Table I. – Explanatory variables and associations with number of Japanese tubesnouts *Aulichthys japonicus*

Variable	Unit	Data type	Description
Seagrass bed area	Ind./m^2	Continuous	Changes of seagrass bed area in every year
Ascidian number	–	Ordinal	High and low
Water temperature	˚C	Continuous	Water temperature on sea surface on May
Spawner number	–	Ordinal	High and low

and during day and night in 2015-2016) in the spring tide during the period from April to December from 2012 to 2016 (a total of 43 months and 86 survey times), and we carried out the sampling twice a month. In addition, sampling was not carried out in May and September in 2016, and we used the data collected during the period from April to December from 2007 to 2008 to compare with the data after the Tsunami. The fishes were preserved in 10% sea-water formalin or 70% sea-water ethanol. The specimens were identified according to Okiyama (2014). We observed the morphology with a microscope (SZX12: Olympus, Tokyo, Japan). We also counted the number of ascidians on the sea-wall during the period from 2011 to 2016 using SCUBA diving.

Classification

The fish samples were classified into three types according to Iwai (2004) and Okiyama (2014) as follow: larva: from hatching to when each fin reaches the fixed ray number; juvenile: when almost all characters have reached those of adult specimens although parts of body are still at an early stage; and young: when they look like adults, although they are not able to reproduce and have an imperfect form as adults. We excluded adults.

Environmental variables

We measured the water temperature (°C), salinity (psu), turbidity (mg/l) and pH using a portable water quality meter WQC-24 (TOA-DKK, Tokyo, Japan).

Statistical analysis

In order to select the best model to explain the change in the number of tubesnouts (response variable), we used AIC (Akaike's Information Criterion) based on GAM (Generalized Additive Model). We prepared several explanatory variables based on the survey results conducted from 2007 to 2008 and from 2012 to 2016. I: the seagrass bed area (m^2) was estimated as 3000 m^2 for the period before the Tsunami according to Yamaki (2009). We also estimated the seagrass bed area for the period after the Tsunami according to Katayose *et al*. (unpubl.). II: the ascidian number on the sea-wall for the period before the Tsunami was assumed as about 10 individuals/m^2 according to Sato (pers. comm.). III: the number of adult (spawners) tubesnouts (High or Low, indicating absence or presence). IV: water temperature in May (spawning season). In addition, combinations of explanatory variables were limited to two variables in this study, because of the low level of degrees of freedom. The lower AIC value indicates the best model for estimating the response variable. This analysis was conducted using R ver.0.3.3.

RESULTS

During the study period in the study site the water temperature ranged from 8.8 to 26.1°C. Salinity ranged from 29.2 to 35.5 psu and the mean salinity was 32.9 psu. From April to June, the salinity was lower than in other seasons because of the effects of the winter snow thaw and subsequently the rainy season.

From 2012 to 2014, we collected 0.344 individuals/m^2 of Japanese tubesnout *Aulichthys japonicus* (from prelarva to young) out of 1.66 individuals/m^2 fishes representing more than 74 species in 9 families. We found that Japanese tubesnout was a dominant species in the larval and juvenile fish community in the seagrass bed at Namiita Beach (Tab. II). Monthly changes in the number of larval, juvenile and young tubesnouts and water temperature collected at the site in

Table II. – Comparison of relative occurrence % of individuals for dominant species (top 5) in the site collected from 2012 to 2014.

Species name	%	Total number of individuals (N/m^2)
Gymnogobius spp.	24.878	0.409
Aulichthys japonicus	20.924	0.344
Pseudoblennius cottoides	9.124	0.150
Gymnogobius heptacanthus	8.576	0.141
Opisthocentrus tenuis	6.630	0.109

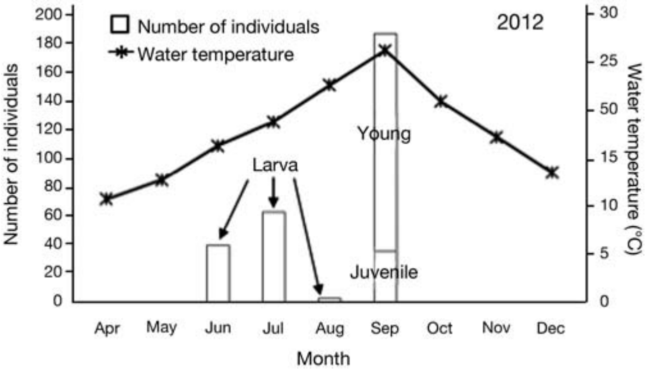

Figure 3. – Monthly changes in the number of individuals for larva, juvenile and young *Aulichthys japonicus* and water temperature collected at the seagrass bed in Namiita beach in 2012.

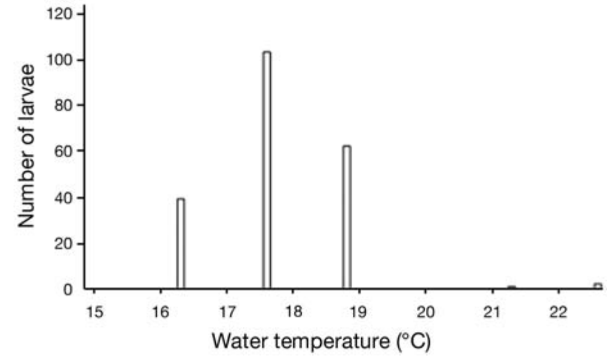

Figure 4. – Relationship between the occurrence of larvae of *Aulichthys japonicus* collected from 2012 to 2013 and water temperature (°C).

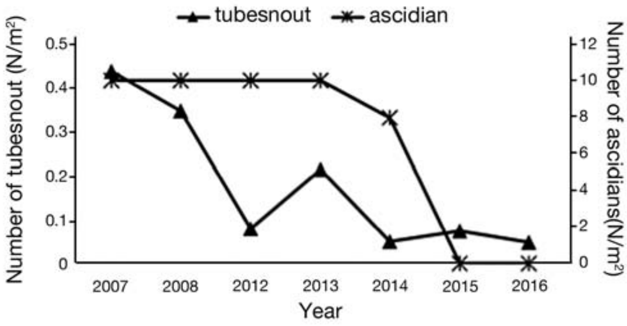

Figure 5. – Changes of number of Japanese tubesnouts *Aulichthys japonicus* and ascidians *Halocynthia roretzi* from 2007 to 2008 and from 2012 to 2016.

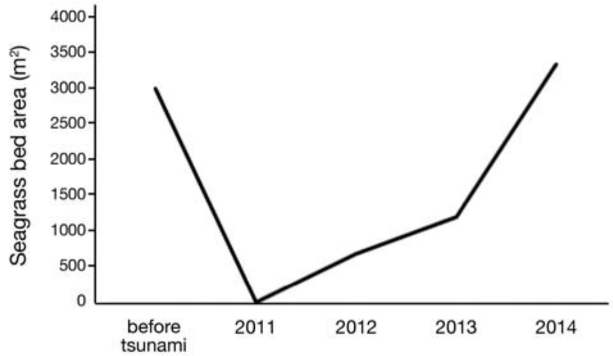

Figure 6. – Changes in the surface of the seagrass bed area (m^2) since before Tsunami (according to Yamaki, 2009) to 2014.

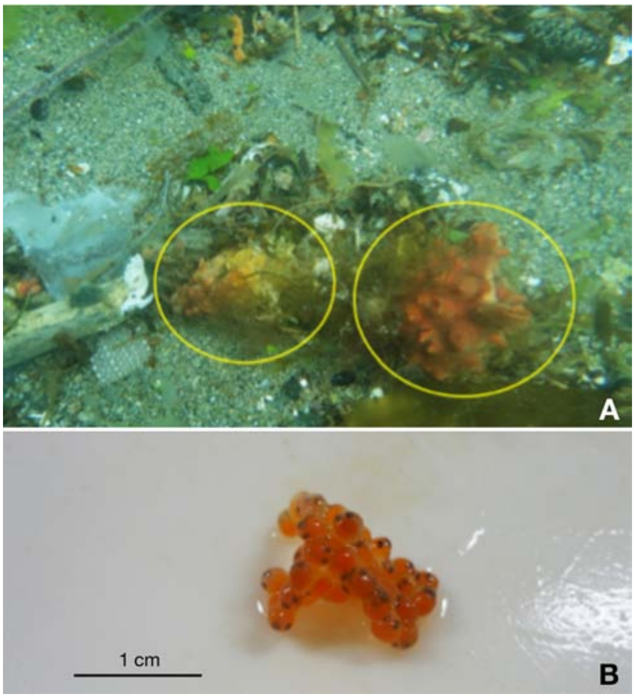

Figure 7. – Photographs showing scraped an ascidian *Halocynthia roretzi* (**A**) and an egg mass (**B**) of the Japanese tubesnout *Aulichthys japonicus*, which was spawned and developed within the ascidians.

2012 are given in figure 3. The larvae, juveniles and young were collected when the water temperature exceeded 15°C, and in other years, we found that 86.6% of larvae appeared during a period when the temperature ranged from 16°C to 18°C (Fig. 4). Changes in larval and juvenile numbers are given in figure 5. They decreased from 0.348 individuals/m^2 in 2008 to 0.080 individuals/m^2 in 2012 (after Tsunami). After, they increased to 0.214 individuals/m^2 in 2013; then they decreased down to 0.050 individuals/m^2 in 2014, and finally remained at a low number until 2016. On the other hand, the seagrass bed area as a nursery for fish has recovered from 0 m^2 just after the Tsunami to ca. 700 m^2 in 2012, ca. 1200 m^2 in 2013 and ca. 3300 m^2 in 2014 (Fig. 6). Almost all ascidians disappeared from the sea-wall (0 individual/m^2) adjacent to the seagrass bed just after the Tsunami. In 2013, the ascidian number increased to 10 individuals/m^2, and the tubesnout number also increased. In 2014, ascidian number locally decreased due to human activities (harvesting) to 8 individuals/m^2. Furthermore on 18th May, 2015, all ascidians growing on the sea-wall (1-5 m; ca. 120 m^2) were scraped off due to reconstruction of the fishery port and were left on the sea bottom. We collected these scraped ascidians and found some egg masses (2 cm wide) in their atrium (Fig. 7). Some eggs were alive and other were dead. We reared the egg masses in an aquarium and studied the hatched larvae to confirm the species name.

Table III shows the values of Akaike's Information Criterion (AIC) based on single variables predicting the relative number of Japanese tubesnouts (N/m^2) from some factors. In the model GAM based on a single variable and combination of single variables, the model based on the number of ascidians on the sea-wall and water temperature (AIC = –20.16) showed the lowest value (best model), and both models of the number of ascidians (AIC = –5.96) and water temperature (AIC = –4.81) showed higher value for the single variables.

Table III. – The value of Akaike's information criterion (AIC) based on single variables and combination of single variables predicting the relative number of individuals (N/m^2) of *Aulichthys japonicus* (top 6).

Model	AIC	ΔAIC
Ascidian number + water temperature	–20.16	0
Ascidian number + spawner number	–11.29	8.87
Ascidian number + seagrass bed area	–10.50	9.66
Ascidian number	–5.96	14.20
Water temperature + seagrass bed	–4.98	15.18
Water temperature	–4.81	15.35
Null	–2.95	17.21

DISCUSSION

We collected many tubesnouts ranged between pre-larval and to adult stage in the survey site, indicating that the Japanese tubesnout use the area around the seagrass bed for almost all its life-cycle.

Larvae and juveniles generally appear in the surf zone of Namiita Beach from late May to August (Sato, 2007). In the seagrass bed (this study), larvae, juveniles and young were collected when the water temperature exceeded 15°C (Figs 3-4). Tubesnout embryos need two weeks to hatch (Ida, 1997). Akagawa *et al.* (2008) also reported that tubesnouts spawned between 12°C to 18°C in aquaria. As the spawning season occurs from late March to June in Pusan, Korea (Matsubara, 1971), in June in Otsuchi Bay, Iwate, Japan (Akagawa *et al.*, 2004) as observed in the present study, tubesnouts would hardly be able to reproduce after the 2011 Tsunami because there were only a few ascidians left and no seagrass bed to act as a nursery ground. In 2012, although the number of ascidians had increased (10 individuals/m^2), tubesnout number remained stable, which suggests that either the tubesnouts have been limited in their spawning opportunities, due to the too small size of ascidians (10-30 mm in diameter) , and/or the number of adult tubesnouts was still too small compared to the period preceding the Tsunami. In 2013, tubesnout number increased probably because both increasing of the seagrass bed area and relative abundance of ascidians on the sea-wall. In 2014, the tubesnout number had decreased while the number of ascidians on the sea-wall had also decreased, but not the area of the seagrass bed that had increased (Fig. 6). Usually, fishermen do not collect ascidians on the sea-wall, but they collected them in 2014 because rafts and infrastructures used for the aquaculture of ascidians were completely destroyed by the Tsunami. Since the spawning season of tubesnout overlaps with the harvesting season of ascidians, we assumed that many eggs in the atrium of ascidians were removed along with the ascidians. In the next year, we found on the sea-bottom many ascidians that had been scraped off the sea-wall and could sample egg masses of tubesnout from 22 of the 71 scraped ascidians (body height: 39-88 mm). These eggs were already eyed. We assumed that the decrease of tubesnouts in 2014 and 2015 was linked to the decrease of ascidians due to human activities, including ascidian harvesting and reconstruction of the sea-wall. We also observed a small number of surviving ascidians (1.3 ind./m^2) within sheltered areas on the rocky shore adjacent to the sampling site (water depth: 5 m) by SCUBA diving just after the Tsunami (August 2011). Although a small number of tubesnout larvae and juveniles were collected in 2012, they originated from eggs spawned into ascidians that survived on the rocky shore, because their lifespan is limited to two years at the longest (Ida, 1997).

In order to verify these assumptions about the Tsunami effects on dynamics of the tubesnout larvae and juveniles population, we compared some explanatory variables using AIC. Table III showed the models in which the values were lower than Null model (average value). The model (GAM) based on a single variable showed a relationship with the occurrence of tubesnout. However, the model based on the ascidian number on the sea-wall showed the best prediction, in contrast to the model based on the seagrass bed area. It is suggested that changes in the ascidian number affected tubesnout number most strongly. On the other hand, the model (GAM) based on a combination of single variable showed a relationship with ascidian number and water temperature, and ΔAIC values of the other models differed from the best model (ascidian number + water temperature) by more than two. It is also suggested that changes of ascidian number and sea condition affected the tubesnout number. As a result of the present study, it is thought that the decrease of ascidians is more effective than the decrease of seagrass area for reducing the Japanese tubesnout number under the condition surveyed. It is also suggested that human activities such as restoration work can disturb the natural recovery from the disaster. However, these disturbances can be considered as secondary, indirect effects of the great Tsunami on the coastal ecosystems. Since many restoration works are being conducted along the coastline of east Japan, we have to pay attention to conserving environmental conditions such as fish nurseries. Shoji and Morimoto (2016) reported that changes in habitat (sea-bottom) conditions due to the Tsunami led to changes in dominant fish species in Mangoku-ura Bay. However, there are few reports on the effects of restoration work on resilience of the ecosystems that have been critically affected by natural disasters. Therefore, it is thought that an environmental assessment before any restoration work in damaged areas is needed.

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